

Final Report

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Early Precambrian Carbonate and Evapolite Sediments:
Constraints on Environmental and Biological Evolution

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FINAL REPORT

NASA Grant NAG5-6722 "Early Precambrian Carbonate and Evaporite Sediments: Constraints on Environmental and Biological Evolution"

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The work accomplished under NASA Grant NAG5-6722 "Early Precambrian Carbonate and Evaporite Sediments: Constraints on Environmental and Biological Evolution" was very successful. Our lab was able to document the occurrence and distribution of evaporite-to-carbonate transitions in several basins during Precambrian time, to help constrain the long-term chemical evolution of seawater.

Project 1: Carbonate precipitation in a Proterozoic hypersaline basin

A unique tufa and stromatolite succession, represented by the uppermost 10 m of the ~1.8 Ga Hearne Formation (Pethei Group), northern Canada, developed across a large carbonate platform during a transition from normal marine to evaporitic conditions. In ascending order, the facies which document this transition consist of dendritically branching tufa, irregularly laminated flat to domal stromatolites and even, isopachously laminated domal stromatolites. The morphologies and textures of these tufas and stromatolites are similar to structures produced in heavily mineralized depositional environments (e.g. hot-spring and hypersaline depositional systems). Comparison with structures produced in the mineralizing systems, as well as with laboratory experiments of biological growth and abiotic mineral precipitation provide insight into the mechanistic processes which contributed to development of the unusual facies of the uppermost Hearne Formation.

This comparison suggests the Hearne tufa and stromatolites were formed by biotic and abiotic processes whose influence on morphology fluctuated during the deposition of these facies. The key to understanding the dominant role that abiotic processes played in development of these unusual carbonate fabrics lies in recognizing that these features formed during a transition from normal marine to evaporite conditions when seawater became warmer, increasingly saline, and more conducive to *in situ* mineralization. The tufa facies and domal, isopachously laminated stromatolite facies are both considered to have resulted from abiotic precipitation of carbonate mud induced by progressive oversaturation of seawater associated with increasing temperature and salinity during restriction of the Pethei basin. These facies are not observed in normal marine carbonates of this age and younger and so the presence of such extreme environmental conditions are considered essential for the development of this facies. The generic growth mechanism of diffusion-limited aggregation (or similar depositional process) is invoked here to account for growth of micritic, dendritically branching tufa as a dominantly abiotic process. Similarly, domal stromatolites with even, isopachous laminae and evidence for surface normal growth may have been produced primarily by abiotic mineral precipitation of micrite cement at the sediment-water interface. Whether or not micrite precipitation was kinetically aided by the presence of microbes remains uncertain as there is no preserved evidence of such structures. However, the characteristically irregular lamination of the flat to domal stromatolites is most consistent with the former presence of discontinuous microbial mats which would have trapped and bound loose sediment. Abundant precipitation is not indicated in this facies as no calcified sheaths are preserved.

Project 2: Paleoproterozoic Carbonate-to-Halite Transition

Uppermost Pethei Group carbonates, the overlying Stark Formation evaporite collapse-breccia and Tochatwi Formation siliciclastics in Athapuscow Basin, Northwest Territories, Canada record the transition from open marine, carbonate platform deposition into marine siliciclastics and evaporites and non-marine siliciclastics. Breccia occurs directly above both shallow and deepwater carbonates indicating evaporites formed across the platform as well as adjacent basin. Foundered clasts up to 1.5 km long and 40 m thick in basinward settings suggest cumulative evaporite thicknesses on the order of a few tens to a few hundreds of meters. Carbonate clasts in the megabreccia contain abundant wave ripples, planar laminations, stromatolites and ooids indicating shallow subaqueous deposition. A paucity of subaerial exposure features also suggests nearly all deposition occurred subaqueously. Sandstone in the upper part of the Stark Formation thins northward where it interfingers with interbedded siltstone and shale.

Displacive halite pseudomorphs are common throughout all facies in the Stark. Silicified and dolomite-filled halite pseudomorphs are common along the Pethei/Stark contact and surrounding large blocks in basinal settings. Silicified hopper casts within deep water rhythmites of uppermost Pethei Group indicate precipitation of halite in deep water. Gypsum pseudomorphs are very rare, and anhydrite pseudomorphs are not present. The interpreted dominance of halite-bearing marine evaporites in this basin and two penecontemporaneous basins surrounding the Slave craton (Kilihigok and Wopmay Orogen) suggests that seawater circa 1.9-1.8 Ga was highly oversaturated with respect to calcium carbonate and possibly depleted in SO_4^{2-} . The dearth of extensive, thick-bedded marine gypsum in the Archean and Paleoproterozoic can be explained by low atmospheric oxygen content prior to ~2 Ga in conjunction with increased carbonate saturation before ~1.6 Ga.

Project 3: Precambrian versus Phanerozoic Carbonate-to-Evaporite Transitions

The transition between carbonate platforms or isolated carbonate buildups and overlying evaporites commonly is marked by assemblages of stromatolites and interlaminated carbonates and evaporites. Stromatolites display lamination textures that vary from peloidal and discontinuous on a scale of mm to a few cm, to isopachous and continuously laminated on a scale of cm to m. The isopachous lamination texture may be composed of either micritic or radial fibrous calcite and dolomite. Isopachous stromatolitic laminae are remarkably uniform, varying little in thickness over a given lateral distance, in contrast to stromatolites formed of peloidal laminae which show marked variation in thickness over an equivalent lateral distance. These textures are uncommon on most open-marine carbonate platforms and apparently developed in transitional carbonate-to-evaporite settings due to increasing temperature, salinity and anoxia related to water stratification, which would have created ecologic restriction and an opportunity for stromatolite growth. Stromatolites with isopachous lamination are here interpreted to have formed as a result of *in situ* precipitation of sea-floor encrusting calcite and possibly dolomite, whereas the stromatolites comprised of peloidal, discontinuous lamination are inferred to have formed by trapping and binding of loose carbonate sediment in microbial mats. While the presence of microbes in almost all near-surface environments nullifies use of the term “abiotic” to describe most precipitated minerals, we interpret growth of the isopachous stromatolites to have been dominated by chemogenic precipitation in the absence of microbial mats, and the

growth of peloidal stromatolites to have been controlled by sedimentation in the presence of microbial mats.

These transitional stromatolite facies are best developed atop Proterozoic and Paleozoic carbonate platforms that underlie major evaporite successions. However, inspection of Jurassic and younger evaporite basins, such as the Messinian of the Mediterranean region, shows that stromatolites with fine, isopachous lamination and radial fibrous textures, though present, are rare. Instead, these facies may have been replaced by stromatolites with peloidal, clastic textures and by low-diversity diatomaceous and coccolith mudstones. Accumulation of the mudstones would have imposed two important effects. In the first instance, production of coccoliths would have helped extract calcium carbonate from seawater, thus lowering the growth potential for precipitation of sea-floor encrusting stromatolites. In the second case, settling of both coccoliths and diatoms would have created a sediment flux to the sea floor which would have served to impede growth of precipitated stromatolites due to smothering of growing crystals.

Publications in major journals resulting from these three projects:

- Grotzinger, J. P and Knoll, A. H. 1999. Stromatolites: Evolutionary mileposts or environmental dipsticks? *Annual Reviews of Earth and Planetary Science*, v. 27, p. 313-358
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- Pope, M. C., and Grotzinger, J. P., 2000, Controls on fabric development and morphology of tufa and stromatolites, uppermost Pethei Group (1.8 Ga), Great Slave Lake, northwest Canada, *in*, SEPM Special Publication - Carbonate Sedimentation and Diagenesis in the Evolving Precambrian World, J. Grotzinger and N. James (eds), p. 103-122.
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- Pope, M. C., and Grotzinger, J. P., In Press. Carbonate-to-Evaporite transition in the Great Slave Lake Supergroup, Athapuscow Basin, Northwest Territories, Canada: Implications for Paleoproterozoic ocean chemistry. *Journal of Sedimentary Research*.